LFV B decays in generic Z' models

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in collaboration with

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arXiv:1504.07928

Workshop “Novel aspects of $b \to s$ transitions”

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Motivation

- Tensions in
  - $B \to K^* \mu^+ \mu^-$
  - $R(K) = \mathrm{Br}(B \to K\mu^+\mu^-)/\mathrm{Br}(B \to K e^+ e^-)$
  - $B_s \to \phi \mu^+ \mu^-$
- Can be explained by new physics in the effective operator

$$\mathcal{O}_9^{\mu\mu} = \frac{\alpha}{4\pi}[\bar{s}\gamma^\mu P_L b][\bar{\mu}\gamma_\mu \mu]$$

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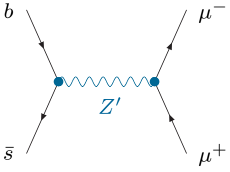
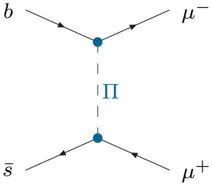
- Natural NP cadidates inducing this operator at tree level:



Z' models

Buras et al;
Altmannshofer,Gori,Pospelov,Yavin;
Crivellin,D'Ambrosio,Heeck; ...



lepto-quarks

Hiller,Schmaltz;
Gripaios,Nardecchia,Renner; ...

LFV Z' coupling?

- solve $B \to K^* \mu^+ \mu^-$ anomaly and R_K tension simultaneously

  $\Rightarrow$ Z' couples to muons but not electrons

- Z' model violates lepton universality

  $\Rightarrow$ natural to assume also presence of LFV $Z'\tau\mu$ coupling

- search for LFV decays $B_s \to \tau\mu$, $B \to K^{(*)}\tau\mu$

  [Glashow,Guadagnoli,Kane]

  $\Rightarrow$ measurable effects possible?

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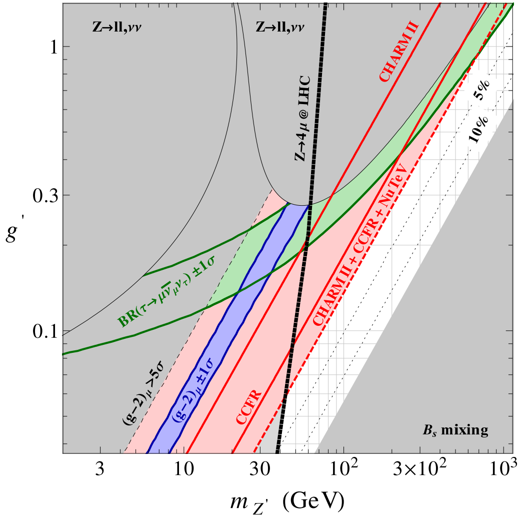
  [Glashow,Guadagnoli,Kane]

  $\Rightarrow$ measurable effects possible?

- study most general framework: arbitrary couplings

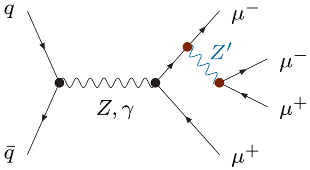
$$Z' sb : \Gamma_{sb}, \qquad Z' \mu\mu : \Gamma_{\mu\mu}, \qquad Z' \tau\mu : \Gamma_{\tau\mu}$$

Constraints on generic $Z'\mu^+\mu^-$ coupling

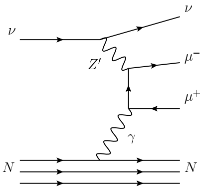


[Altmannshofer,Gori,Pospelov,Yavin arXiv:1403.1269]

Atlas signature:



Neutrino tridents



Two scenarios

solution of $b \to s\mu^+\mu^-$ anomalies necessarily requires large

$$C_9^{\mu\mu} \propto \Gamma_{sb}^L \Gamma_{\mu\mu}^V$$

assume $\Gamma_{sb}^R \ll \Gamma_{sb}^L \quad \Rightarrow \quad C_9', C_{10}' \sim 0$

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$\boxed{V}$ vectorial coupling to leptons: $\quad \Gamma_{\ell\ell'}^L = \Gamma_{\ell\ell'}^R = \Gamma_{\ell\ell'}^V$

generated WC: $C_9^{\ell\ell'}$

fit to $b \to s\mu^+\mu^-$ data: see talk by J. Virto

4.6σ pull$_{\text{SM}}$ at 1σ: $C_9^{\mu\mu} \in [-1.33, -0.91]$

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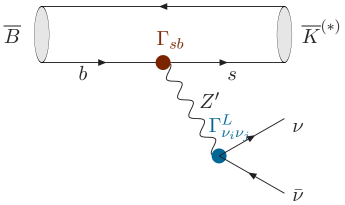
$\boxed{L}$ left-handed coupling to leptons: $\quad \Gamma^L_{\ell\ell'} = \Gamma^V_{\ell\ell'}, \quad \Gamma^R_{\ell\ell'} = 0$

generated WC: $C_9^{\ell\ell'} = -C_{10}^{\ell\ell'}$

fit to $b \to s\mu^+\mu^-$ data: see talk by J. Virto

3.9σ pull$_{\text{SM}}$ at 1σ: $C_9^{\mu\mu} = -C_{10}^{\mu\mu} \in [-0.89, -0.50]$

Constraint from $B \to K^{(*)} \nu\bar{\nu}$



$SU(2)_L$ invariance: $\Gamma^L_{\nu_i\nu_j} = \Gamma^L_{\ell_i\ell_j}$

$$C_L^{\nu_i\nu_j} = (C_9^{\ell_i\ell_j} - C_{10}^{\ell_i\ell_j})/2$$

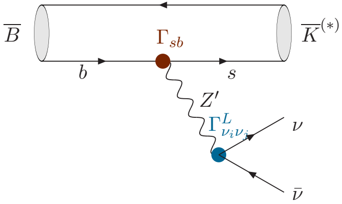
Branching ratio (normalised to SM prediction):

$$R^{\nu\bar{\nu}}_{K^{(*)}} = \frac{1}{3}\sum_{i,j=1}^{3} \left|C_L^{ij}\right|^2 \Big/ \left|C_L^{\rm SM}\right|^2$$

$R^{\nu\bar{\nu}}_{K} < 4.3$ (BarBar)

$R^{\nu\bar{\nu}}_{K^*} < 4.4$ (Belle)

Constraint from $B \to K^{(*)}\nu\bar{\nu}$



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V $C_L^{\nu_i\nu_j} = C_9^{\ell_i\ell_j}/2 \quad \Rightarrow \quad |C_9^{\mu\tau}| < 46$

$${\rm Br}[B \to K^*\tau\mu] \approx {\rm Br}[B_s \to \tau\mu] \approx {\rm Br}[B \to K\tau\mu] < 8 \times 10^{-5}$$

L $C_L^{\nu_i\nu_j} = C_9^{\ell_i\ell_j} \quad \Rightarrow \quad |C_9^{\mu\tau}| = |C_{10}^{\mu\tau}| < 23$

$${\rm Br}[B \to K^*\tau\mu] \approx {\rm Br}[B_s \to \tau\mu] \approx {\rm Br}[B \to K\tau\mu] < 2 \times 10^{-5}$$

Constraints in lepton sector

- $\tau \to 3\mu$: $\Gamma^2_{\mu\tau}\Gamma^2_{\mu\mu}$

  Belle + BarBar (90% conf. lev.): $\mathrm{Br}(\tau \to 3\mu) < 1.2 \times 10^{-8}$

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  $\mathrm{Br}_{\mathrm{exp}} = (17.39 \pm 0.04)\%$, $\mathrm{Br}_{\mathrm{SM}} = (17.29 \pm 0.03)\%$ [Pich]

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- loop corrections to $Z \to \ell\ell'$: $\Gamma^2_{\mu\tau}$, $\Gamma^2_{\mu\mu}$, $\Gamma_{\mu\tau}\Gamma_{\mu\mu}$

  LEP: $\mathrm{Br}(\mu^+\mu^-) = (3.366 \pm 0.007)\%$, $\mathrm{Br}(\tau^\pm\mu^\mp) < 1.2 \times 10^{-5}$

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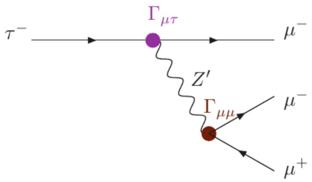
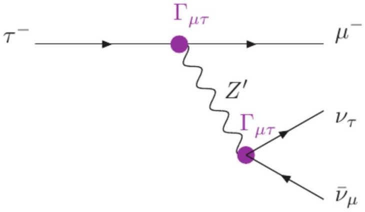
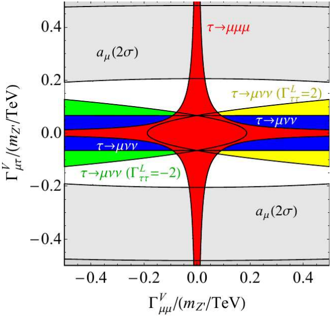
- neutrino tridents $\nu_\mu N \to \nu_\ell N \mu^+\mu^+$: $\Gamma^2_{\mu\mu}$, $\Gamma^2_{\mu\tau}\Gamma^2_{\mu\mu}$
  [Altmannshofer,Pospelov,Gori,Yavin]

  combined bound from CHARM-II/CCFR/NuTeV:
  $\sigma_{\mathrm{exp}}/\sigma_{\mathrm{SM}} = 0.83 \pm 0.18$

Lepton couplings

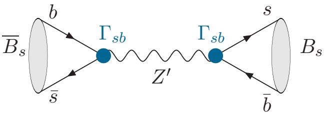






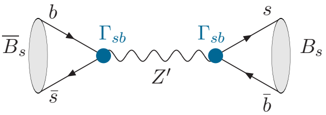
vectorial $Z'\ell\ell'$ coupling

Strategy of our analysis



1 Constrain Γ_{sb}
from $B_s - \overline{B}_s$ mixing

Strategy of our analysis



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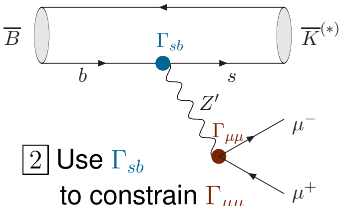

2 Use Γ_{sb}

to constrain $\Gamma_{\mu\mu}$

from $B \to K^{(*)}\mu^+\mu^-$

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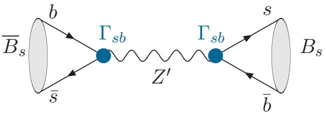

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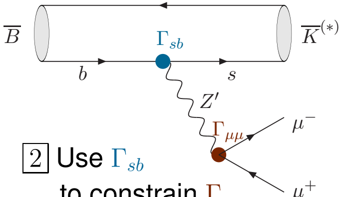

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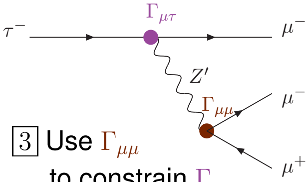
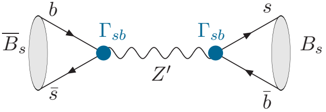


3 Use $\Gamma_{\mu\mu}$

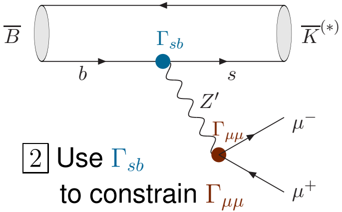
to constrain $\Gamma_{\mu\tau}$

from $\tau^- \to \mu^-\mu^+\mu^-$

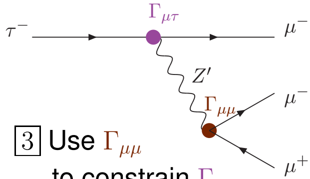
Strategy of our analysis



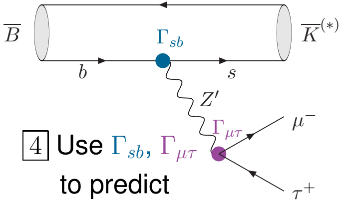
$\boxed{1}$ Constrain Γ_{sb}
from $B_s - \overline{B}_s$ mixing



$\boxed{2}$ Use Γ_{sb}
to constrain $\Gamma_{\mu\mu}$
from $B \to K^{(*)}\mu^+\mu^-$

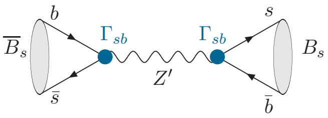


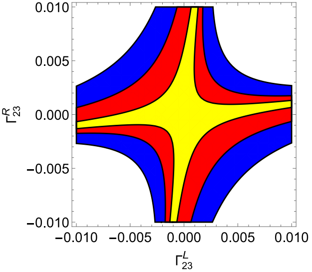
$\boxed{3}$ Use $\Gamma_{\mu\mu}$
to constrain $\Gamma_{\mu\tau}$
from $\tau^- \to \mu^-\mu^+\mu^-$



$\boxed{4}$ Use Γ_{sb}, $\Gamma_{\mu\tau}$
to predict
$B \to K^{(*)}\tau^+\mu^-$
$\Rightarrow$ Large effects possible?

$B_s - \overline{B}_s$ mixing





- contributions from left- and righthanded Z' couplings:

$$(\Gamma^L_{sb})^2 + (\Gamma^R_{sb})^2 - b_{B_s}\Gamma^L_{sb}\Gamma^R_{sb}$$

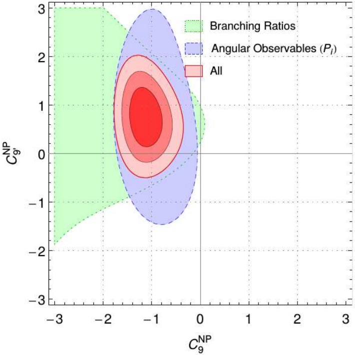
- solution of $B \to K^*\mu^+\mu^-$ anomaly requires non-zero Γ^L_{sb}

- constraint from $B_s - \overline{B}_s$ mixing can be softened by same-size coupling Γ^R_{sb} with $\Gamma^R_{sb} \ll \Gamma^L_{sb}$:

  fine-tuning measure: $X_{B_s} = \dfrac{(\Gamma^L_{sb})^2 + (\Gamma^R_{sb})^2 + b_{B_s}\Gamma^L_{sb}\Gamma^R_{sb}}{(\Gamma^L_{sb})^2 + (\Gamma^R_{sb})^2 - b_{B_s}\Gamma^L_{sb}\Gamma^R_{sb}}$

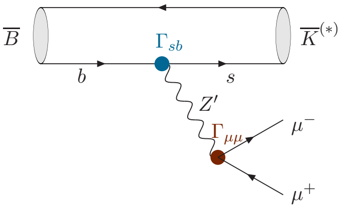
Right-handed coupling Γ^R_{sb}

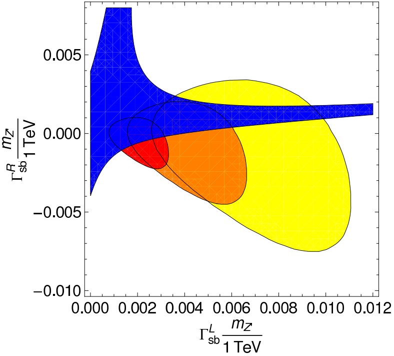
- same-size coupling Γ^R_{sb} with $\Gamma^R_{sb} \ll \Gamma^L_{sb}$ requires same-size $C'_9 \ll C_9$
- global fit to $b \to s\mu^+\mu^-$ data (see talk by J. Virto)



- same-size $C'_9 \ll C_9$ not favoured by the fit but possible at 2σ level

$B \to K^{(*)}\mu^+\mu^-$



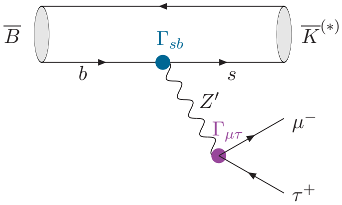


$\Gamma_{\mu\mu} = 1.0$, $\Gamma_{\mu\mu} = 0.5$, $\Gamma_{\mu\mu} = 0.3$

- $C_9^{\text{NP}} \sim \Gamma^L_{sb}\Gamma_{\mu\mu}$, $C_9'^{\text{NP}} \sim \Gamma^R_{sb}\Gamma_{\mu\mu}$

- small $\Gamma_{\mu\mu}$ requires large Γ^L_{sb} and because of the correlation with $B_s - \overline{B}_s$ mixing a small same-size Γ^R_{sb}

$B_s \to \tau\mu, \quad B \to K^{(*)}\tau\mu$



$$C_{9,10}^{(\prime)\tau\mu} \propto \Gamma_{bs}^{L(R)} \Gamma_{\mu\tau}^{V,A}$$

$$\begin{aligned} \text{Br} \;&=\; a\,|C_9^{\tau\mu} + C_9^{\prime\tau\mu}|^2 + b\,|C_{10}^{\tau\mu} + C_{10}^{\prime\tau\mu}|^2 + \\ & \quad c\,|C_9^{\tau\mu} - C_9^{\prime\tau\mu}|^2 + d\,|C_{10}^{\tau\mu} - C_{10}^{\prime\tau\mu}|^2 \end{aligned}$$

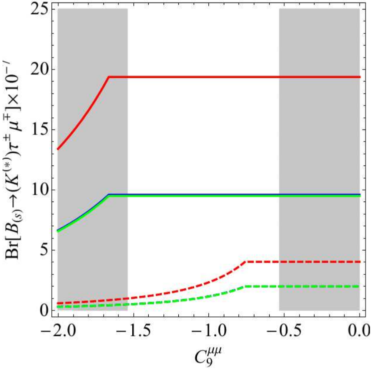
- $B_s \to \tau\mu$: $\quad a = b = 0, \quad c \approx d$
  $B \to K\tau\mu$: $\quad a \approx b, \quad c = d = 0$
  $B \to K^*\tau\mu$: $\quad a \approx b, \quad c \approx d$

- experimental bounds:

$$\text{Br}\left(B^+ \to K^+\tau^\pm\mu^\mp\right) \le 4.8\times10^{-5}\,, \qquad \text{Br}\left(B^+ \to K^+\mu^\pm e^\mp\right) \le 9.1\times10^{-8}\,,$$
$$\text{Br}\left(B \to K^*\tau^\pm\mu^\mp\right) \le --\,, \qquad \text{Br}\left(B \to K^*\mu^\pm e^\mp\right) \le 1.4\times10^{-6}\,,$$
$$\text{Br}\left(B_s \to \tau^\pm\mu^\mp\right) \le --\,, \qquad \text{Br}\left(B_s \to \mu^\pm e^\mp\right) \le 1.2\times10^{-8}$$

$B_s \to \tau\mu$ and $B \to K^{(*)}\tau\mu$

Max. branching ratio of $B_s \to \tau\mu$, $B \to K^*\tau\mu$, $B \to K\tau\mu$
tuning B_s mixing to $X_{B_s} = 100$ (solid), $X_{B_s} = 20$ (dashed)



constraints from

- $\tau \to 3\mu$: $\propto\ (1 + X_{B_s})^2/|C_9^{\mu\mu}|^2$
- $\tau \to \mu\nu\bar{\nu}$: $\propto\ (1 + X_{B_s})$

$B_s \to \mu e$ and $B \to K^{(*)}\mu e$

- Stringent bound on $\mu \to e\gamma$:

$$\mathrm{Br}_{\mathrm{exp}} = 1.2 \times 10^{-14} \qquad \text{(MEG Coll.)}$$

$\mu \to e\gamma$: $\propto (1 + X_{B_s})^2/|C_9^{\mu\mu}|^2$

$\Rightarrow$ BRs for LFV B decays $< \mathcal{O}(10^{-9})$ (for $X_{B_s} = 100$) in the $C_9^{\mu\mu}$ region favoured by current $b \to s\mu^+\mu^-$ data

$B_s \to \mu e$ and $B \to K^{(*)}\mu e$

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- Larger BRs possible for $C_9^{\mu\mu} \to 0$

require $\Delta\mathrm{Br}[\mu \to e\nu\bar{\nu}] \; < \; 4 \times 10^{-5}$

restricts corrections to Fermi-constant to the sub per-mille level

$\mu \to e\nu\bar{\nu}$: $\quad \propto \; (1 + X_{B_s})$

$\Rightarrow$ BRs for LFV B decays $\lesssim \mathcal{O}(10^{-7})$ (for $X_{B_s} = 100$)

Conclusions

- we have studied the possible size of $B_s \to \ell\ell'$, $B \to K^{(*)}\ell\ell'$ with $\ell\ell' = \tau\mu, \mu e$ considering
  - two scenarios with vectorial and left-handed $Z'\ell\ell'$ couplings
  - existing constraints on $Z'\ell\ell'$ couplings
- sizable effects require cancellations in $B_s - \overline{B}_s$ mixing implying non-vanishing $C'^{\mu\mu}_{9,10}$ with $C'^{\mu\mu}_{9,10} \ll C^{\mu\mu}_{9,10}$ (if $Z'\mu\mu$ does not vanish)
- For $\tau\mu$ final states branching ratios can be up to $\sim \mathcal{O}(10^{-6})$ for a fine-tuning of $X_{B_s} \sim 100$ in $B_s - \overline{B}_s$ mixing
- For μe final states branching ratios can only be up to $\sim \mathcal{O}(10^{-7})$ for a fine-tuning of $X_{B_s} \sim 100$ in $B_s - \overline{B}_s$ mixing, and this only in a region of parameter space disfavoured by $b \to s$ anomalies